

A. Project Title: DEVELOPMENT OF A WATER QUALITY MODELING TOOL BOX TO INFORM POLLUTANT REDUCTION PLANNING, IMPLEMENTATION PLANNING AND ADAPTIVE MANAGEMENT

B. Theme and Sub-theme: Water Quality; Water Quality Modeling

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E. Total Funding Requested: \$338,311

F. Total Value of In-kind Contribution: \$37,900

II. Proposal Narrative

a. Justification Statement

Continuous, long-term evaluation of water quality in Lake Tahoe (CA-NV) over the past 40 years has documented a decline of clarity at the alarming rate of 0.22 m (~0.7 feet) per year (TERC 2007) (Fig. 1). This long-term loss of transparency is both statistically significant ($p < 0.001$; Jassby et al. 1999; 2003) and perceptible to the human eye. This rate of clarity loss will be accompanied by a lasting change in both the Lake's renown cobalt-blue color and trophic status; signs of both are already evident (Richards pers. comm.; Chandra et al. 2005). Extensive research at the University of California, Davis, has demonstrated that scattering of light by particulate matter contributes ~80% to light attenuation; 60% of this is the result of fine inorganic sediment derived from watershed soils and 20% due to organic particles primarily algae (e.g. Jassby et al. 1999; Coker 2000; Rabidoux 2005; Swift et al. 2006). Absorption by water molecules, dissolved organic matter and phytoplankton caused the remaining ~20% of the light attenuation. Fine particles (<15-20 μm) accounted for nearly all of the light scattering (Swift et al. 2006). Urban runoff is responsible for 70-75% of total fine particle loading (Roberts and Reuter 2007).

The three agencies with regulatory authority over lake water quality conditions in the Tahoe basin (Tahoe Regional Planning Agency [TRPA], California – Lahontan Water Board and Nevada Division of Environmental Protection [NDEP]) have all codified numeric and narrative targets for water quality protection of the Lake and its tributaries. In addition, concentration limits have been applied to protect the quality of stormwater runoff. California has designated Lake Tahoe as an Outstanding National Resource Water affording it with the highest level of antidegradation under the federal Clean Water Act, while Nevada has adopted the designation of "*water of extraordinary value*" (reviewed in Roberts and Reuter 2007). Additionally, the TRPA has developed numeric water quality thresholds, and implemented programs and regulations for water quality/clarity protection.

During the past decade tens of millions of dollars have been spent annually on a host of environmental restoration and water quality control projects intended to abate the clarity loss. This became formalized during the 1997 Lake Tahoe Presidential Forum as the Environmental Improvement Plan (EIP), a conservation strategy to heal past environmental damage by the implementation of capital improvement projects (TRPA 2007). A combination of restoration efforts, purchase of environmentally sensitive lands, and regulatory actions forms the basis for water quality protection.

Prior to 2001, lake management was based on, (1) water quality standards that reflected historic conditions, (2) data from a lake/tributary monitoring program, (3) a sound scientific understanding of Lake Tahoe's limnology and (4) a conceptual understanding of the relationship between lake disturbance and pollutant loading – but without quantitative estimates of load reduction needs and expected lake response. In 2001, California Water Board and NDEP began work on a TMDL (Total Maximum Daily Load) for Lake Tahoe; in essence, a science-supported water quality management plan that provides quantitative pollutant load reduction targets needed to meet lake clarity goals. This quantitative approach of the TMDL recognized that the conceptual approach to lake management used prior to 2001 was inadequate for management into the future (Reuter and Miller 2000). Questions such as what is the relationship between a particular land-use and pollutant loading, how much of a pollutant reduction is needed to achieve the desired clarity standards, and what are the expected levels of pollutant reduction based on restoration/BMP opportunities basin-wide, all require quantitative answers.

With the Tahoe TMDL program, the need for mechanistically-based, management models to address the questions above was recognized (Reuter et al. 1996; Reuter and Miller 2000; Roberts and Reuter 2007). Since 2001, the TMDL program has spearheaded the development of a series of models that can be used for water quality planning. These models represent first-generation versions that have either been developed specifically for use in the Tahoe basin or have taken existing, peer-reviewed products and customized them to account for local conditions. The basin regulatory agencies have committed to the use of a modeling approach to inform pollutant reduction planning, implementation planning and adaptive management. Currently, many of the models are so new that there has been insufficient time/funding for

technology transfer, packaging in user-friendly manner, creating linkages between models, further validation, and applying linked models to fully answer key management questions.

b. Background and Problem Statement

In 2004, the TMDL program began to develop the *Tahoe Water Quality Tool Box* (Roberts et al. 2004). The *Tool Box* was intended to incorporate models and other tools that can be used by agencies, resource managers, planners, scientists, engineers, and EIP project implementers to help plan for achieving basin-wide load reduction goals. The use of agreed-to models provides an opportunity for conformity in water quality planning. The *Tool Box* is intended to provide a forum for the development and application of the tools identified as needed for both water quality planning and implementation, develop and apply these tools so that they are integrated and compatible, be user-friendly and readily updated, provide an established framework for new models to conform to, and inform an adaptive management framework. The intent is that it be fashioned after the national U.S. EPA TMDL Modeling Toolbox (U.S. NERL, Athens, GA). The EPA modeling toolbox is a collection of models, modeling tools and databases. While each model, tool and database is a stand-alone application, this product is designed to promote exchange of information through common linkages. There is a similar vision for the Lake Tahoe program (Roberts et al. 2004). While the ultimate goal is to have these models linked to the extent possible and packaged for general use this has yet to be formalized.

Models used in water quality planning at Lake Tahoe include: a customized lake clarity model that directly links lake response (Secchi depth) to pollutant loading (Perez-Losada 2001; Sahoo et al. 2006); a watershed model using the Load Simulation Program in C++ (LSPC) (Tetra Tech 2007); atmospheric transport and deposition modeling (CARB 2006); stream channel erosion modeling using Conservational Channel Evolution and Pollutant Transport System (CONCEPTS) (Simon et al. 2003); a stormwater pollutant load reduction model driven by Storm Water Management Model (SWMM) (nhc & GeoSyntec 2006); a groundwater flow model using MODFLOW (Fenske and Shatila 2003); a three-dimensional (3-D) lake circulation model to evaluate nearshore-offshore pollutant transport (Si3D) (Smith 1997; Rueda et al. 2003); a two-dimensional (2-D) floodplain/water quality (SIFT2D-WQ) (Andrews 2007), the Weather Research and Forecasting model (WRF) (<http://www.wrf-model.org/index.php>); and a spreadsheet Packaging and Assessment Tool (PAT) to optimize load reduction and cost scenarios (Tetra Tech unpub.). Examples of model output and process schematics for selected model are shown in Figures 2-4 with a summary in Figures 5 and 6. The current SNPLMA Round 8 RFP also calls for the development of a Lake Tahoe atmospheric modeling system to evaluate management strategies to improve air quality and reduce the impact of atmospheric deposition of fine particles and nutrients to the lake surface. Thus management models will be available for each of the major sources of fine sediment and nutrients important to Lake Tahoe (Roberts and Reuter 2007).

Currently, the models in the *Tahoe Water Quality Tool Box* share the following major shortcomings. They (1) can only be run by their respective developers, (2) the recent proliferation of models used to support the Tahoe TMDL has rapidly out-stripped our ability to organize them for convenient future use, and (3) there is no clear protocol for review and updating based on new knowledge. With this grant we will work with the TMDL agencies to remedy this situation and begin to develop model linkages that can enhance our ability to answer key water quality management questions.

c. Goals, Objectives and Hypotheses to be Tested

Using the modeling tools that have been developed, those under current revision, or those being developed, the goals of this project are to (1) work with the water quality regulatory agencies to formally develop the envisioned *Tahoe Water Quality Tool Box*, (2) package selected models to include user-friendly protocols, documentation and application formats, leading to a means for technology transfer to Basin users, (3) create conceptual and operational linkages between individual models as appropriate, and (4) update the Watershed Model to better address the critical issue of wildfire and pollutant runoff. It is recognized by both researchers and environmental managers that the use of models for water quality planning at Lake Tahoe has just started with the current TMDL effort (Roberts and Reuter 2007). This

proposal is intended to extend this process by using the *Tool Box* concept to help organize and integrate the current loose confederation of models. This proposal is not intended to physically create all possible model linkages nor address all management questions; it will however establish a framework for future model development, application and revision.

The specific objectives are:

1. Review the performance of both the LSPC Watershed Model and Lake Clarity Model with regard to meteorology, stream loading and lake clarity on the basis of new observational data collected since 2004 when the models were initially validated.
2. Ready the Watershed Model and Lake Clarity Model for transfer to agencies by creating a user-friendly packaging format.
3. Develop a computational linkage between the Lake Clarity Model and the UC Davis 3-D lake circulation model using regional meteorology output from WRF.
4. Develop a computational linkage between the project-scale Pollutant Load Reduction Model and the basin-scale LSPC Watershed Model.
5. Update Watershed Model to better evaluate impact of wildfire on hydrology and loading.
6. Develop a data product to house meteorology inputs used in water quality modeling.

d. Approach, Methodology and Location of Research

1. Review the performance of both Watershed and Lake Clarity Model Since Initial Validation

The Watershed Model is currently calibrated through December 2004. We propose to extend the meteorological forcing data through water year 2007, to provide three additional snowfall/snowmelt hydrologic cycles. This involves obtaining and processing new Snowfall Telemetry (SNOTEL) datasets and National Climatic Data Center (NCDC) surface airways observations from nearby stations. Observed datasets of interest include precipitation, temperature, dew point, wind speed, and cloud cover. Solar radiation and potential evapotranspiration are computed from observed data constituents. The meteorological datasets will be reviewed for accuracy and disaggregated to an hourly time-step as needed, for incorporation within the LSPC modeling framework. Relevant nearshore MET gages will be reviewed and transposed into a format suitable for use by the Clarity Model for the same time period.

The US Geological Survey and the Lake Tahoe Interagency Monitoring Program also have additional years of tributary monitoring, which would be used for hydrology and water quality validation. The extended watershed time series will also represent an extended upland boundary condition for the Lake Clarity Model. These three years include two relative wet years (2006 was the second wettest year in the last 20 years). The extended upland boundary conditions, together with new Secchi depth readings through 2007 are key components for additional validation of the clarity model.

2. User-friendly Packaging of Watershed and Lake Clarity Models

Watershed Model - The Lake Tahoe Watershed Model is a customized application of the Loading Simulation Program in C++, or LSPC (Shen, et al. 2004; LSPC, 2003). LSPC is a watershed modeling system that includes Hydrologic Simulation Program-FORTRAN (HSPF) algorithms (Bicknell et al. 1997) for simulating watershed hydrology, erosion, and water quality processes, as well as in-stream transport processes. The algorithms of LSPC are identical to a subset of those in the original HSPF model; however, this newer system provides a Windows integrated development and database management platform that is ideal for integrating large spatial and tabular datasets like those compiled for the Tahoe Watershed Model. As part of the model packaging and technology transfer to agency staff, the following tasks and products are proposed:

- A compiled LSPC Model application with associated database and post-processing software,
- A complete set of the underlying Tahoe-specific spatial (GIS) and tabular datasets that were assembled and developed for the Tahoe Watershed Model,

- A detailed user's manual of the current model including a detailed description of all the relevant model processes and functions associated with the Lake Tahoe customization,
- Organization and execution of a training course that would be open to staff from multiple agencies. The training course would be tailored towards model application and hypothetical scenario development, with example exercises.

It is envisioned that a final deliverable will be a fully indexed CD or DVD containing all electronic data associated with the listed tasks and deliverables. Tetra Tech will also work with the agencies to prepare these materials for dissemination through Agency websites and/or other data portals. The products resulting from this effort represent a significant data resource and technology advancement that will benefit future studies within the Tahoe basin.

Lake Clarity Model - The Lake Clarity Model is a specially developed version of the general water quality model DLM-WQ (e.g. Hamilton and Schladow 1996; Schladow and Hamilton 1996; McCord et al. 1998; McCord et al. 2000; Heald et al. 2005; Swift et al. 2006). It is written in Fortran, and currently entails approximately 3000 lines of code. Adding new processes to the model, or even modifying the details of existing processes is difficult, and something that is unlikely to be accomplished by agency staff without advanced knowledge in numerical modeling and lakes physics.

It is therefore not realistic to provide Agency staff with the full source code at this time. Rather, compiled code will be provided that could be more easily used by Agency staff. As modifications and improvements to the model are made, updates to this product will be provided. For this to be a workable means of having Agency staff run these models, UC Davis will develop the following three products:

- a) A detailed manual of the current model will be produced, including the model architecture, detailed descriptions of all sub-routines and functions, and specifications for all required input variables. This latter item will be reviewed and refined in collaboration with the developers of models that supply input to this model (i.e., the hydrology model, the atmospheric model, the storm water model, the floodplain model etc.) to ensure that the inputs and outputs of each model are consistent. If necessary, a program for preparing the necessary input data for the clarity model from the output of the other models will be produced.
- b) A post-processor for handling model output will be produced. Currently the output of the clarity model is used for a range of research purposes, and it is frequently customized to meet specific needs. Through consultation with Agency staff, a set of graphical output formats will be produced, to enable agency staff to produce standard output products in readily available forms such as Excel. A standardized output format for all model output variables will be produced to enable Agency staff to customize output if necessary.
- c) Running the clarity model for a 20-year simulation currently takes over 6 hours on a high-end workstation. Frequently, agency staff wish to explore a large range of project specific options, and are interested in obtaining approximate answers as a means to narrow the options prior to a detailed investigation. For this purpose we will develop a Clarity Model estimator. Rather than running the full model, the Estimator is an Excel based tool that is based on regressions from a detailed set of model runs. The data input will be highly generalized, and entered via a set of pull-down menus. In a matter of several minutes a particular option could be run and the output indicate whether it is worthy of further consideration through use of the full model. This tool will also provide the agencies with an effective outreach tool, as the Estimator could be made available to the public and allow them to simulate possible improvements to lake water quality.

3. Clarity Model and 3-D Circulation Model Linkage

The one dimensional (1-D) lake clarity model and the three-dimensional (3-D) lake circulation model have both been developed using data from Lake Tahoe and both have performed well. The 1-D model has the advantages of being relatively rapid to run (6 hours for a 20 year simulation) and having complete

water quality, ecological and optical sub-models. Its disadvantage is that it cannot represent spatial variability in the horizontal direction, and for that reason is indicative of generalized conditions in the open-water. The 3-D model on the other hand is far slower to run (1 month in 6 hours) but can represent conditions throughout the lake (at least to the model discretization level, typically 200 m x 200 m x 4 m). As part of a separate project, water quality sub-models are currently being incorporated into the 3-D model, so the opportunity now exists to produce 3-D predictions of water quality.

What is proposed here is to run the models for the same time period with the same input data and explore the differences in the model results. The advantages of this are as follows:

- A better understanding of the response of the 1-D model will be obtained, thereby increasing confidence in its ability to act as a planning tool,
- Only the 3-D model can represent the linkages between the mid-lake and the near-shore regions. By running both models we can study whether current efforts to address mid-lake quality (clarity) will have any beneficial impacts on the near-shore,
- Past use of both models has been based on interpolation of meteorological forcing data from a few stations around the basin. It is proposed to drive both models with downscaled meteorological data from the WRF model. This far more intensive model input (e.g. windfields applied at 200 m grid scales) will indicate whether past modeling efforts had input data of sufficient resolution.

4. Project-scale Pollutant Load Reduction Model and Basin-scale LSPC Watershed Model Linkage

The Pollutant Load Reduction Model (under development by **nhc**) and the Tahoe Watershed Model (developed by Tetra Tech) are designed to estimate pollutant loads at different spatial scales (roughly 40 vs. 80,000 hectares, respectively). The Pollutant Load Reduction Model estimates load reductions associated with implementation of individual urban storm water projects (urbanized project scale); the Tahoe Watershed Model estimates pollutant loading from the entire Tahoe basin (watershed scale).

As part of the Tahoe TMDL, **nhc** and Tetra Tech developed a generalized approach that classified urban sub-watersheds into representative settings according to primary features that drive the selection and placement of BMPs, such as the configuration of impervious area and land slope. The setting approach was used to extrapolate generalized performance estimates of project-scale pollutant load reductions to the scale of sub-watersheds in the Watershed Model. This approach was sufficient to estimate overall pollutant load reductions associated with uniform levels of urban storm water project implementation as a component of the Tahoe TMDL program. However, the setting approach cannot readily inform the Watershed Model to represent specific planned or implemented urban storm water projects, which may be quite variable in design and performance. A more explicit and efficient computational linkage is needed for this purpose. Specific research questions to be addressed by this proposal include:

- What scalar effects should be represented in application of more detailed project load reduction estimates in models at the sub-watershed or watershed scale? For example, are load reductions in tributary catchments simply additive?
- How can functional differences associated with resolution in the two models (e.g., single BMP vs. BMP'd drainage catchment) be resolved or bridged to produce relatively consistent results?
- What are the key factors or variables that must be translated from project-scale modeling to watershed-scale modeling to adequately represent project specific effects?
- What level of computational linkage is most feasible, accurate, and efficient? For example, is direct output/input linkage practical, or is translation or conversion of results at the project scale to revised input data at the sub-watershed scale sufficiently accurate and more practical? If the latter, how should results at the project scale be translated?

nhc will work with Tetra Tech to answer the above research questions and develop a technical approach for using urban storm water project-scale modeling to inform Watershed Model simulations at the sub-watershed and basin scale. A specific approach will be developed and tested in two sample sub-

watersheds represented by the Watershed Model. **nhc** will lead development of the technical approach and algorithms or convert output from the Pollutant Load Reduction Model into compatible formats and structure to aggregate the performance of multiple individual storm water quality improvement projects in basin-scale modeling of load reductions.

5. Update of Watershed Model to Address Wildfire

Existing Representation: The US Forest Service (Lake Tahoe Basin Management Unit) and the California Tahoe Conservancy compiled map layers for prescribed fires and wildfire regions for different events over the period 1996-2004. These map layers also included the degree of burning within each affected area. For each burned area, these agencies also computed Equivalent Roaded Area (ERA) values. ERA is a watershed disturbance index commonly used by the USFS (e.g. McGurk and Fong 1995) and represents the area of road surface that would produce the same effect as the burn activities. The event mean concentrations (EMCs) for pollutants draining from burned areas were assumed to be the same as for unpaved roads as required by the ERA approach. The Watershed Model uses the calculated ERA areas and unpaved road EMCs with the LSPC hydrologic sub-routine to estimate load. A 6-year linear recession curve to zero-impact was used to compute the diminishing effects of the burns over time (McGurk et al. 1996). The magnitudes were then averaged over the calibration period to estimate a recovery-adjusted ERA for each burned region. The GIS land-use ‘burned’ layer accounted for only 0.20% of the entire 812 km² drainage, the result of effective fire suppression since the early 1900s (Heyvaert 1996) and included the 272 hectare Gondola Fire near the Heavenly Ski Resort – the largest wildfire until the 2007 Angora Fire that burned nearly 1,255 hectares.

The areas of uncertainty identified with the ERA approach included the assumption of unpaved road behavior (due to lack of detailed fire monitoring data), and the literature estimated fire recession curve. With the recent advent of the large Angora Fire basin agencies are much more sensitized to updating the Watershed Model to address drainage from burned areas with increased confidence.

Proposed Enhancements: These include (1) compile and review recent monitoring and fire impact evaluation literature, (2) investigate hydrologic impacts of burned areas from literature and monitoring (i.e. hydrophobic ground cover), (3) improve representation of burned area runoff concentrations for fine sediment, total nitrogen, and total phosphorus using burned area runoff monitoring data, (4) improve representation of stream delivery for fire-related runoff using pre- and post-fire in-stream monitoring data (Tt), (5) perform analysis of post-fire monitoring data and review related literature to improve the representation of fire recovery, and (6) update model configuration and perform validation runs to confirm the response of the revised approach using in-stream monitoring from the Angora Fire. UC Davis will contribute to #1, 2, 3, 5 while Tetra Tech will contribute to #3, 4, 5, 6. Fine sediment and nutrient sampling downstream of the Angora Fire is now underway and will provide monitoring data.

6. Meteorology Data Product for Water Quality Modeling

Hydrologic processes are time-varying and depend on changes in environmental conditions including precipitation, temperature and wind speed. For the watershed and lake clarity models, hourly time steps for MET data is required to properly reflect diurnal temperature changes. For snow simulation, the Watershed Model uses temperature to decide whether precipitation should be considered as rainfall or snowfall. For the Tahoe basin additional data (temperature, dew point temperature, wind speed and solar radiation) are needed for snow simulation. Likewise, the Lake Clarity Model requires similar MET data for simulation runs.

There are two primary data sources for locally observed weather data. One source is a series of nine SNOwpack TELemetry (SNOTEL) gages in and around the Tahoe basin maintained by USDA. These record air temperature, precipitation, and snow water equivalent data. The other data source is the National Climatic Data Center (NCDC). When linking and running water quality models it is essential to have a uniform data set for MET that can be used for consistency. Using available MET information, a data product will be developed for inclusion in the *Tool Box*. This data will be used to establish a uniform

set of model input for simulation runs (e.g. establish an agreed upon sequence of precipitation for simulation runs). Without this consistency, model results could differ simply due to different MET input data and add unnecessary uncertainty to management applications of the models.

e. Strategy for Engaging With Managers

The three water quality regulatory agencies are in agreement regarding the use of models for water quality planning and implementation and have promoted a modeling framework since 2001. The TMDL agencies and those groups implementing BMP-related projects recognize the importance of conformity in water quality planning that an integrated modeling approach can provide. This later feature is critical in that it provides a set of common and agreed upon methodologies, e.g. crediting, evaluation of basin-wide load reduction, reliable load reduction estimates, and evaluation of watershed and lake response. UC Davis, Tetra Tech and **nhc** have all mutually interacted with the TMDL agencies to develop many of the *Tool Box* models. As the Tahoe TMDL Science Coordinator, Dr. John Reuter will continue to serve as a liaison between research products and agency needs. The members of the research team have been meeting with agency staff and management many times each month during the past four years. This close level of direct interaction will continue as models are packaged, agency staff engage in their application, and the TMDL implementation action progress.

f. Deliverables/Products

1. Conceptual models of the key environmental process related to pollutant load to Lake Tahoe and how they are accounted for in the various simulation models,
2. Updated watershed model with regard to wildfire and pollutant loading. This enhanced model component will be used to simulate loading and lake response from the 2007 Angora Fire,
3. Performance review of watershed and lake clarity models using recent data,
4. Documentation of linkage format for (a) Pollutant Load Reduction Model at the projects scale to basin-scale watershed model and (b) the 3-D lake circulation model to the Lake Clarity Model and regional WRF MET output,
5. Packaging and training for watershed and lake clarity model use by agencies,
6. Data product for MET data/output used in water quality modeling,
7. Framework for formal establishment and operation of the *WQ Tool Box*,
8. Quarterly progress reports, and annual report at the end of year one and a final project report,
9. Participation in the TMDL, Pathway 2007 and other WQ planning efforts that use modeling.

g. Schedule of Milestones/Deliverables

TASK	Month from Start of Project																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1. Start-up meeting and workplan	█																							
2. Create conceptual models	█	█	█																					
3. Performance evaluation of watershed & lake models		█	█	█	█	█	█																	
4. Water and lake model updates and runs				█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
5. Linking 3-D circulation and clarity model				█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
6. Linking Pollutant Load Reduction and watershed models			█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█
7. Packaging and transfer																								
a. watershed model																								
b. clarity model																								
8. MET data product		█	█	█	█	█	█	█																
9. Framework for establishing <i>Tool Box</i>			█	█	█	█	█		█	█				█	█	█	█	█	█	█	█	█	█	█
10. Quarterly Report and Invoice			█				█			█			█			█			█			█		█
11. Agency meetings - project dedicated			█				█			█			█			█			█			█		█
12. Draft Final Report																						█		█

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III. Figures

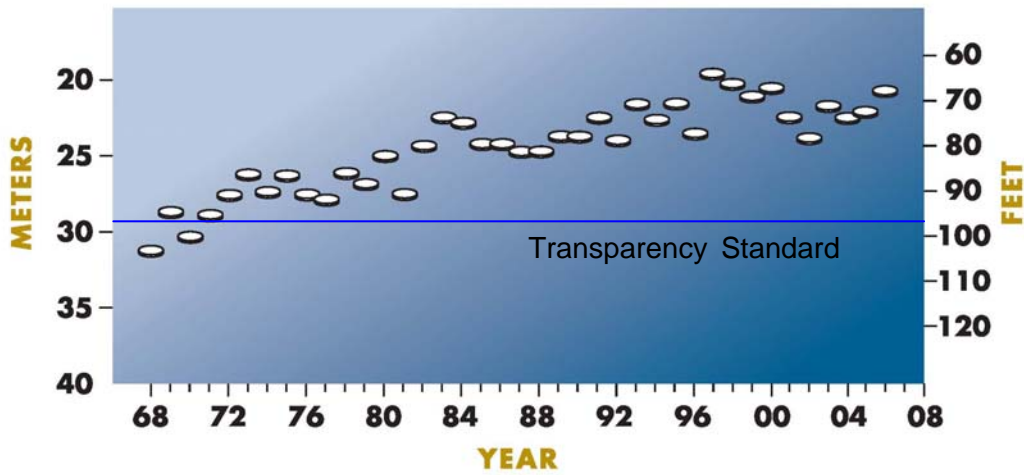


Figure 1. Long-term average annual Lake Tahoe clarity as measured using a 10-cm Secchi disk (data from UC Davis – Tahoe Environmental Research Center). Approximately 30-35 individual measurements are typically taken throughout the year. Standard deviations denote seasonality in clarity. Shorter term trends of apparent improvement or decline have statistically been shown to be related to interannual changes in precipitation and discharge (Jassby et al. 2003). Line of best fit has a slope of -0.22m/yr , $r^2=0.77$, $p<0.001$ with $n=39$. Transparency standard is the management target for annual Secchi depth.

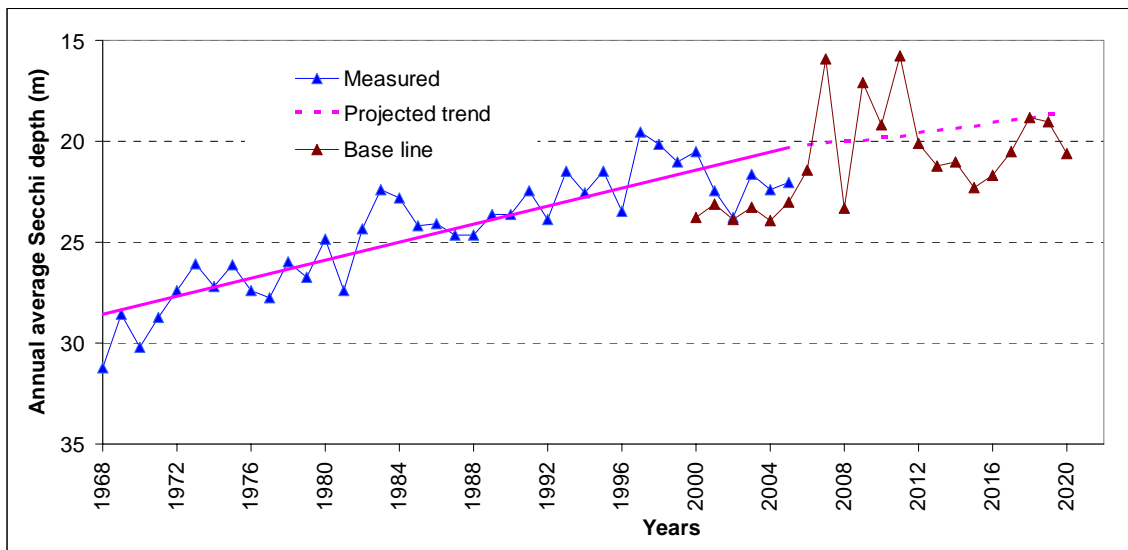


Figure 2. Example of Lake Clarity Model simulation. Measured (blue) and model baseline (red) Secchi depths for 2000-2020 (Red line represents line of best fit while dashed red line represents to line of best fit for the simulated results). 1999-2004 represents calibration/validation period. Changes in lake response resulting from various management scenarios can be compared to baseline or current conditions (from Sahoo et al. 2006).

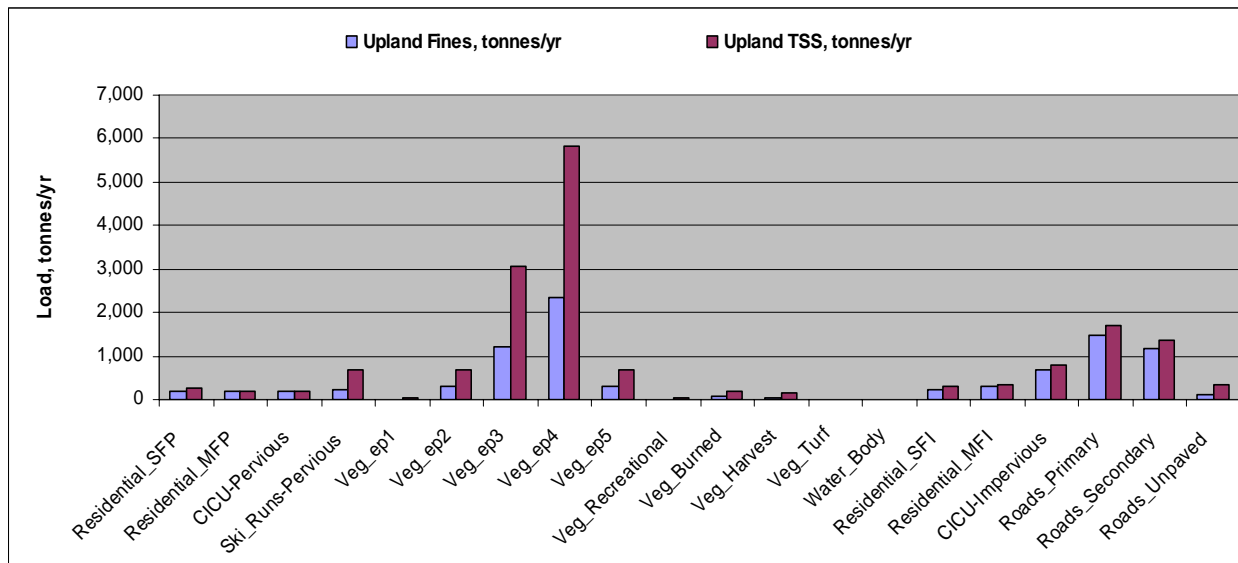


Figure 3. Example of Tahoe Watershed Model-LSPC simulation. Upland TSS and upland fine sediment loading (< 63 μm) by land use category over the 1994-2004 calibration/validation period (from Tetra Tech, Inc. 2007).

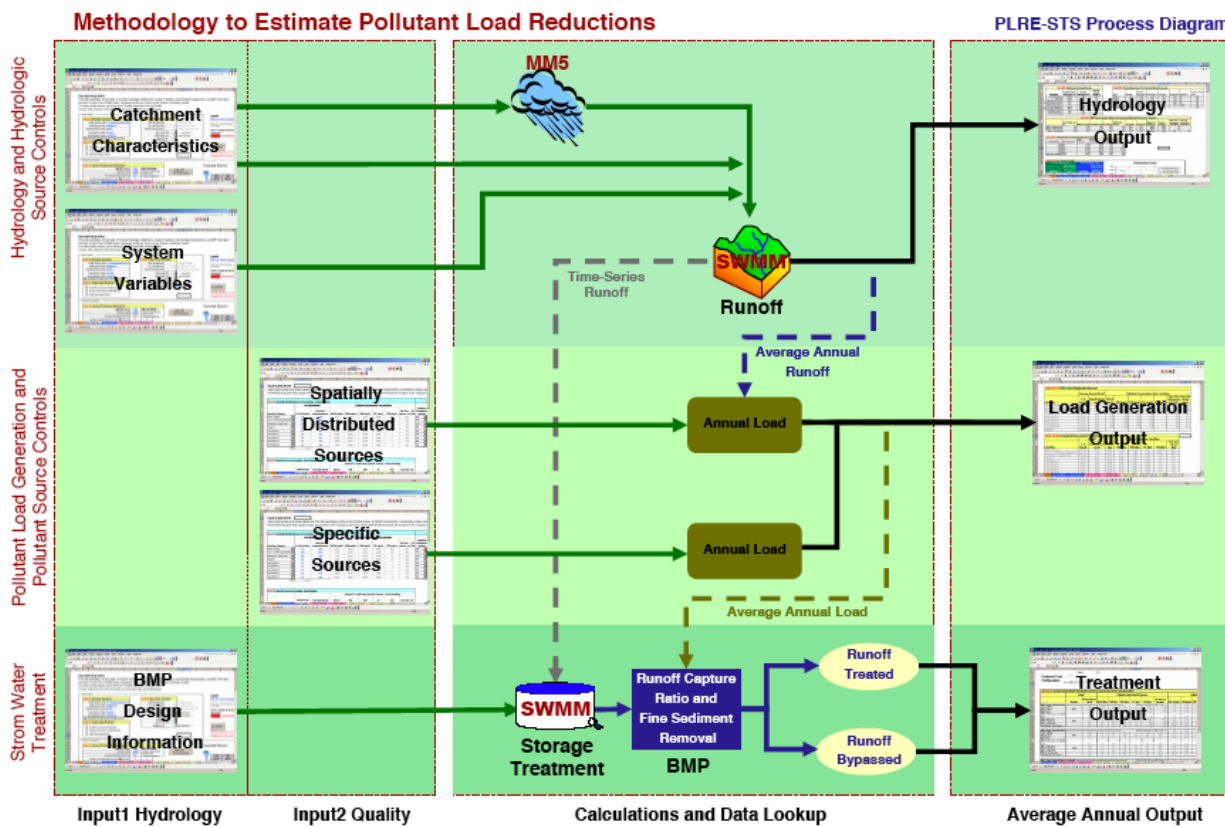


Figure 4. Process schematic for Tahoe's Pollutant Reduction Model (from **nhc** and GeoSyntec 2006).

Model - Tool
<p><u>Lake Clarity Model</u> – UC Davis Lake Clarity Model (LCM) is a unique combination of sub-models including a hydrodynamic model, an ecological model, a water quality model and an optical model. This model was developed to specifically identify Lake Tahoe’s response to fine sediment and nutrient loading, and the pollutant reductions necessary for the protection of lake clarity. It is a 1-D model that uses loading data from the Watershed Model and other sources, and currently supports the TMDL.</p>
<p><u>Watershed Model</u> – Tetra Tech, Inc. has developed the Lake Tahoe Watershed Model by customizing the Loading Simulation Program in C++ (LSPC). The watershed modeling system includes algorithms for simulating hydrology, sediment and water quality from over 20 land-use types in 184 sub-watersheds. This model has been used to estimate the pollutant loading to the lake from surface runoff from the Basin’s 63 channelized streams and numerous intervening zones.</p>
<p><u>Atmospheric Deposition and Transport Modeling</u> – In support of the TMDL the California Air Resources Board used a modeling approach to estimate on-lake deposition of particulate matter and nutrients. A tiered, climatological approach was used measure ambient air quality measurements, literature values for deposition velocity, improved temporal resolution using beta attenuation monitoring and historical hourly MET data, time resolved wind and temperature data and model wind fields. The SNPLMA Round 8 RFP is calling for a more detailed management model for air quality.</p>
<p><u>Stream Channel Erosion</u> – The USDA National Sedimentation Laboratory used their CONCEPTS model to evaluate the significance of stream channel erosion as a source of fine sediment to Lake Tahoe. CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) simulates the evolution of incised streams and to evaluate the long-term impact of rehabilitation measures to stabilize stream systems and reduce sediment yield. CONCEPTS simulates unsteady, one-dimensional flow, graded sediment transport, and bank-erosion processes in stream corridors.</p>
<p><u>Stormwater Pollutant Load Reduction Model</u> – In 2006 a prototype model for assessing site-specific project scale pollutant load reductions from potential BMP implementation was created. This tool (known as the Pollutant Load Reduction Estimator – Spreadsheet for Tahoe Storm Water) includes a hydrologic simulation component, a pollutant load generation component, and a storm water treatment component. It has been used in estimating basin-wide pollutant control opportunities (Lahontan & NDEP 2007) and is expected to help with strategies for pollutant reduction crediting. Efforts to develop a beta-version complete with technology transfer and packaging for agency use are currently being funded.</p>
<p><u>Groundwater Flow Model</u> – In 2003, the USACOE-Hydrologic Engineering Center developed a groundwater flow model to better understand lake-groundwater interaction at Lake Tahoe. Algorithms from MODFLOW SIP and MODFLOW PCG2 were employed in this effort. This numerical model estimates the volume, rate and distribution of groundwater flux to the lake.</p>
<p><u>3-D Lake Circulation Model Si3D</u> – UC Davis scientists published a public domain, 3-dimensional finite-difference model for calculating the time varying, 3-D water circulation in large lakes such as Lake Tahoe (CA-NV), Clear Lake (CA) and the Salton Sea (CA)(e.g. Rueda et al. 2003, 2005). It is currently being used to model circulation in the nearshore of Lake Tahoe with funding from a SNPLMA Round 7 grant.</p>
<p><u>2-D Floodplain Hydrodynamic and Water Quality Model SIFT2D-WQ</u> – UC Davis is developing this model to quantify fine sediment and nutrient removal when streams overtop their banks and spread on adjacent floodplains. Water quality aspects of SWMM are being integrated into this model, that was specifically created for freshwater floodplains to better model flow in the highly advective channel environment with complex topography.</p>
<p><u>Packaging and Assessment Tool</u> – PAT is a database with a spreadsheet user-interface that allow resource managers to quickly calculate the load reductions and costs associated with implementation of pollutant controls for Lake Tahoe water quality.</p>
<p><u>Weather Research and Forecasting Model</u> – WRF is an advanced mesoscale forecast model and assimilation system developed by NCAR at the national level. The model’s overall goal is a next-generation model and assimilation system that will advance both the understanding and prediction of important mesoscale precipitation systems. This model is currently being used as part of an NSF-funded project by UC Davis to provide down-scaled meteorological inputs for Lake Tahoe.</p>

Figure 5. Summary of current models completed or being developed/adapted for use in the *Tahoe TMDL Tool Box*.

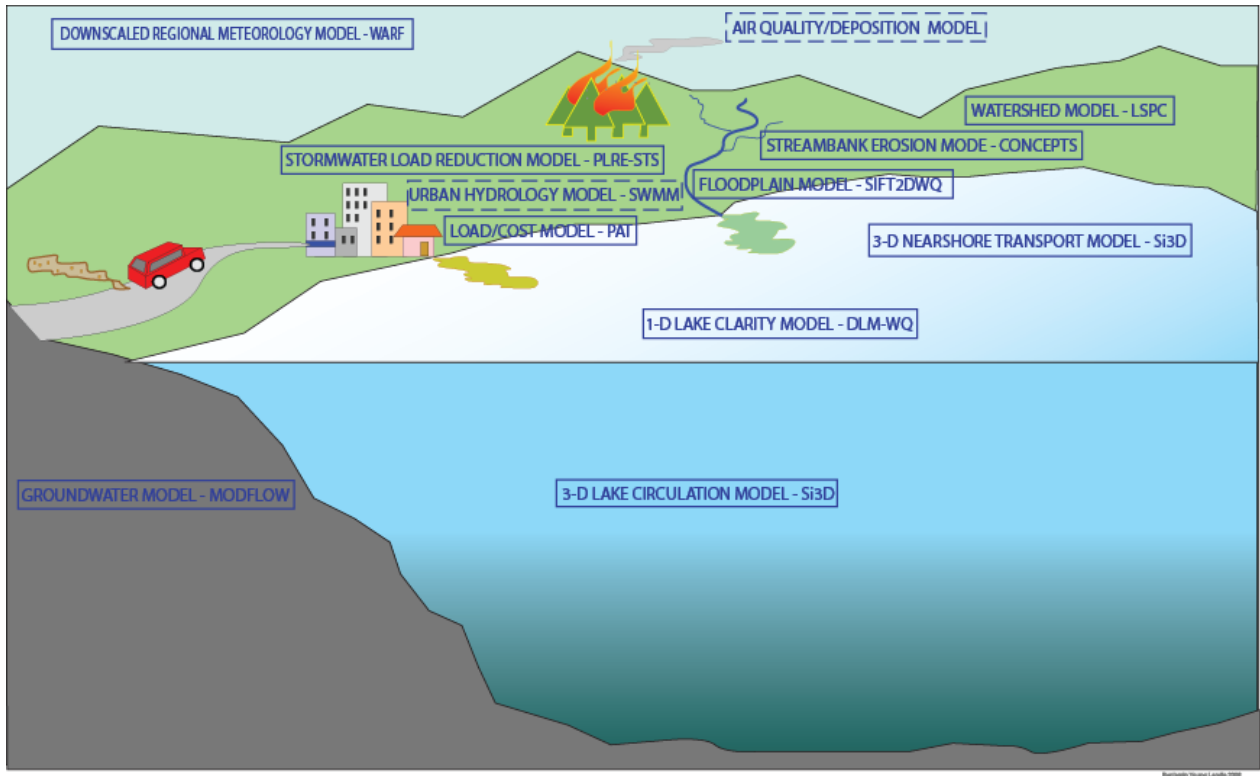


Figure 6. Schematic showing current (solid boxes) and proposed (dashed boxes) models that have been modified or developed for water quality planning at Lake Tahoe. Currently, these models are not linked, documented or organized for easy use by management agencies and the general scientific community.